Note: The following is an expanded text version of Chapter 4 from the *Final Data Report: Noise and Vibration Measurements Associated with the Pile Installation Demonstration Project for the San Francisco-Oakland Bay Bridge East Span*, May 21, 2001, prepared by Illingworth & Rodkin, Inc. The term "Gunderboom" refers to the proprietary fabric barrier system with aerating mechanism.

NMFS MARINE MAMMAL SAFETY ZONE

Because of potential disturbance to marine mammals, an Incidental Harassment Authorization (IHA) from the National Marine Fishery Service (NMFS) was needed and subsequently obtained. This authorization indicated that a safety zone that included all areas where the underwater Sound Pressure Level (SPL) was anticipated to equal or exceed 190 dB re 1 micro Pascal must be established around the pile driving work. The IHA established a 500 meter Initial Safety Zone. This section provides an estimate of the actual distance to the 190 dB level.

Four different acoustical descriptors were used to evaluate underwater noise levels produced by pile driving. Figure D-1 below illustrates the differences between the measurement descriptors used in this evaluation. Underwater noise levels were measured using both a "Peak" detector and a "root-mean-square" or RMS detector. Linear (unweighted) peak levels were measured and reported as "LinPeak" levels. RMS levels were measured and reported using the sound level meter impulse setting (0.031 to 0.035 second time constant) and the RMS "fast" setting on the sound level meter (1/8- [or 0.125] second time constant). Previous studies conducted for NMFS have used an RMS pressure "averaged over the duration of the pulse." The duration of the pulse varies, although the analysis of the time histories of many pulses indicated that most energy occurred within the first 0.030 seconds. Analysis using the RMS impulse setting was a "conservative" estimate of the NMFS criterion since it averages the maximum over a shorter, but louder duration. The following describes the noise descriptors used to evaluate underwater acoustical impulses produced from pile driving:

Linear Peak*: Sound pressure level based on the absolute value of the instantaneous sound pressure*

Lmax RMS "fast": *Maximum root-mean square sound pressure level measured using the 0.125-second exponential time constant*

RMS-Impulse: *Maximum root-mean square sound pressure level measured using the impulse setting of a sound level meter (0.031 to 0.035-second time constant)*

RMS "impulse" NMFS Criterion: *Maximum root-mean square sound pressure level measured over the duration of the pulse evaluated.*

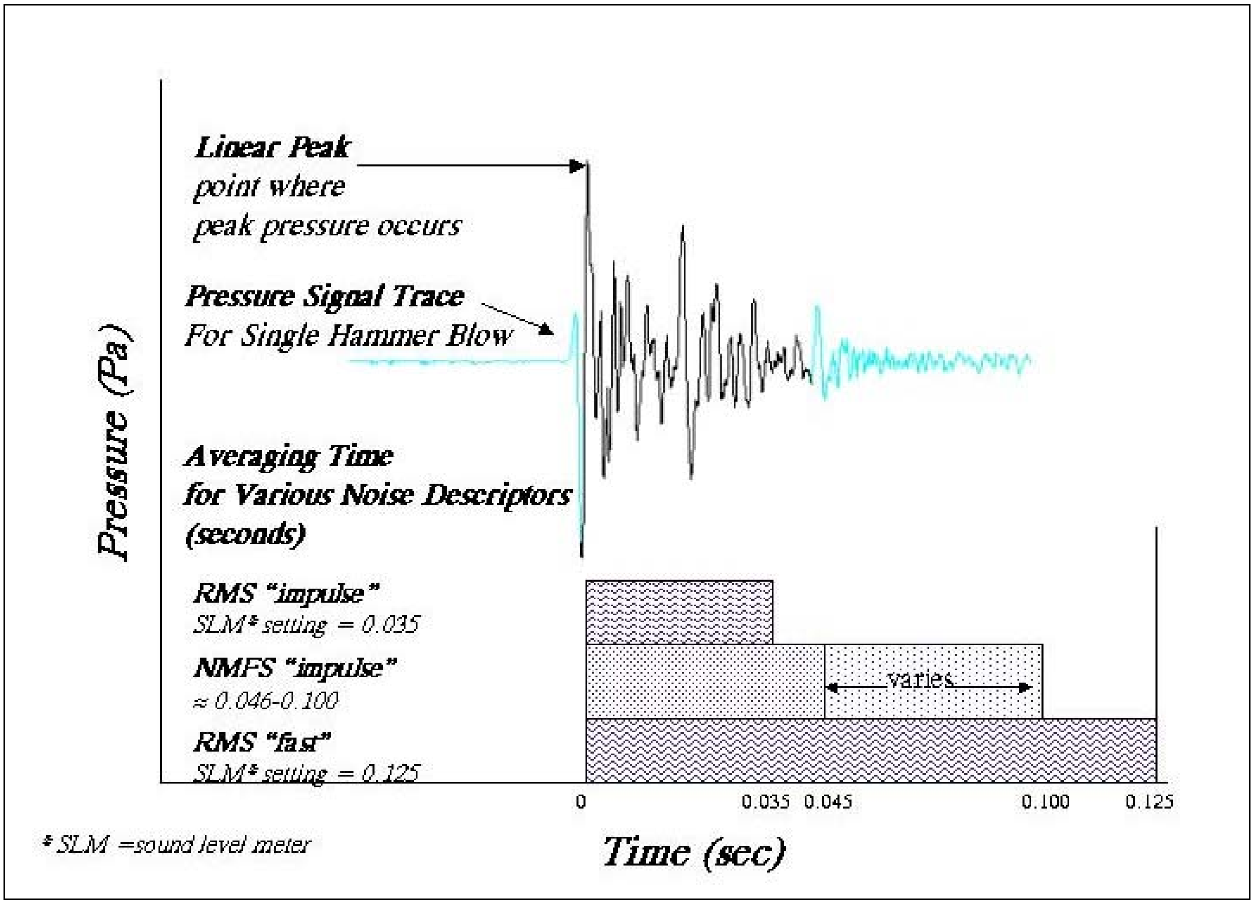


Figure D-1 SFOBB Under Water Pile Driving Noise - Time History of One Strike

The IHA did not exactly specify the noise metric to be used to measure the 190 dB level. Until the measurement unit was confirmed it was recommended that the peak level be used because it would provide the most conservative assessment of the distance out to the 190 dB contour. Subsequent to the publication of the draft of this report (January 26, 2001) additional information was obtained regarding the specifics of the criterion level.[1] In this study various acoustic measurements were conducted. Regarding the criterion level this report states the following:

> "RMS pressure during the pulse. This is the root square of the energy divided by the duration. When presented as a level, in dB re 1 micro Pascal, the RMS pressure level is equivalent to the mean square pressure level of the pulse. This third measure, which might be called the average pulse pressure has been used by BBN [Bolt, Beranek and Newman] in its measurements of air-gun signals (C.I. Malme, personal communication). National Marine Fishery Service criteria concerning apparent reaction thresholds of whales to seismic signals (e.g., NMFS 1995) are based largely on those BBN measurements. RMS pressure levels are expressed in dB re 1 micro Pascal."

[1] Northstar Marine Mammal Monitoring Program, 1996: Marine Mammal and Acoustical Monitoring of a Seismic Program in the Alaskan Beaufort Sea, W. John Richardson, LGO Ltd., and Greeneridge Sciences, Inc. for BP Exploration (Alaska) Inc. and National Marine Fishery Service, August 1997.

The RMS pressure, then, is averaged over the duration of the impulse. The 5 percent of the energy that occurs in the initial rise of the impulse and the 5 percent of the energy that occurs at the final decay of the impulse are excluded from the average. One must, therefore, determine the approximate duration of this impulse in order to correctly measure the RMS average sound pressure level for determination of the 190 dB NMFS level.

Tape recordings of underwater PIDP pile driving were analyzed using various time constants. Most of the energy occurred within the first 30 to 50 milliseconds. To be conservative, a 1/32 second RMS time constant was used to approximate the 190 dB level described above. The data was also processed using a standard “impulse” time constant and found to yield the same result as the 1/32 second RMS time constant.

Dr. Charles Greene, from Greeneridge Sciences, Inc. one of the authors and primary researchers for the referenced study, was consulted regarding the question of the 190 dB criterion level. To confirm that the analysis described above was correctly measuring the level, Dr. Greene graciously agreed to analyze Illingworth & Rodkin, Inc. tape recordings of the pile driving noise using his proprietary software specifically developed to measure NMFS criterion levels. Seventeen different samples representing the different pile driving conditions were analyzed. Figures 9a through 9e show several examples of data analyzed by Greeneridge Sciences. Appendix G (in Illingworth & Rodkin, 2001) includes all of their results. Representative data samples analyzed by Greeneridge Sciences, Inc. were typically 0 to 1 dB lower than results using the 1/32 second RMS or “impulse” time constants. The analysis by Greeneridge Sciences confirmed that the use of these standard time constants for measuring pile driving noise yielded an accurate and conservative measure of the sound level. This conclusion is specific to these pile driving signals and may not be applicable to other types of impulsive underwater noise.

The RMS impulse levels described in Chapter 3 are used to determine the distances to the 190 dB contour during the PIDP pile driving. The highest underwater RMS (impulse) level measured was 196 dB RMS (impulse) re 1 micro Pascal (Pile 1D). During this measurement the hammer energy was 918 kJ during the period when this measurement was made. Very limited data was gathered at or near the maximum hammer energy of approximately 1700 kJ for the large hammer. To account for differences in hammer energy it is assumed that the operational energy of the hammer, and acoustical energy radiated from the pile, are directly proportional in the range of 750 kJ to 1750 kJ (i.e. a doubling in the hammer energy would cause a 3 dB increase in the radiated sound level). It was further assumed that the pile driver would approximate a “point source” at distances beyond 100 meters. The sound level attenuates or drops off at a rate of 6 dB for each doubling of the distance. Also, distant measurements conducted by Illingworth & Rodkin, Inc. indicate that there was excess attenuation of the noise beyond that expected by the standard spherical spreading from a point source. The excess attenuation was 1 dB/51 meters. Because of limitations in the data it cannot be determined whether the excess attenuation would always occur. The distances to the 190 dB contour have been calculated for various hammer energies assuming no excess attenuation (theoretically worst case) and assuming the measured excess attenuation (credible worst case). The calculated distances to the 190 dB contour for the large hammer without attenuation are shown in Table 1 below.

Table 1. Estimated Distance to 190 dB RMS (impulse) Level for 1700 k-Joules Hammer—Without Mitigation

Hammer Energy k-Joules	Distance (Meters) Assuming No Excess Attenuation	Distance (Meters) Assuming Measured Excess Attenuation
750	185	see note
1000	215	see note
1250	240	195
1500	265	210
1750	285	220
Note: It is recommended that the distance to the 190 dB contour should not be assumed to be less than 185 meters regardless of hammer energy or hammer size.		

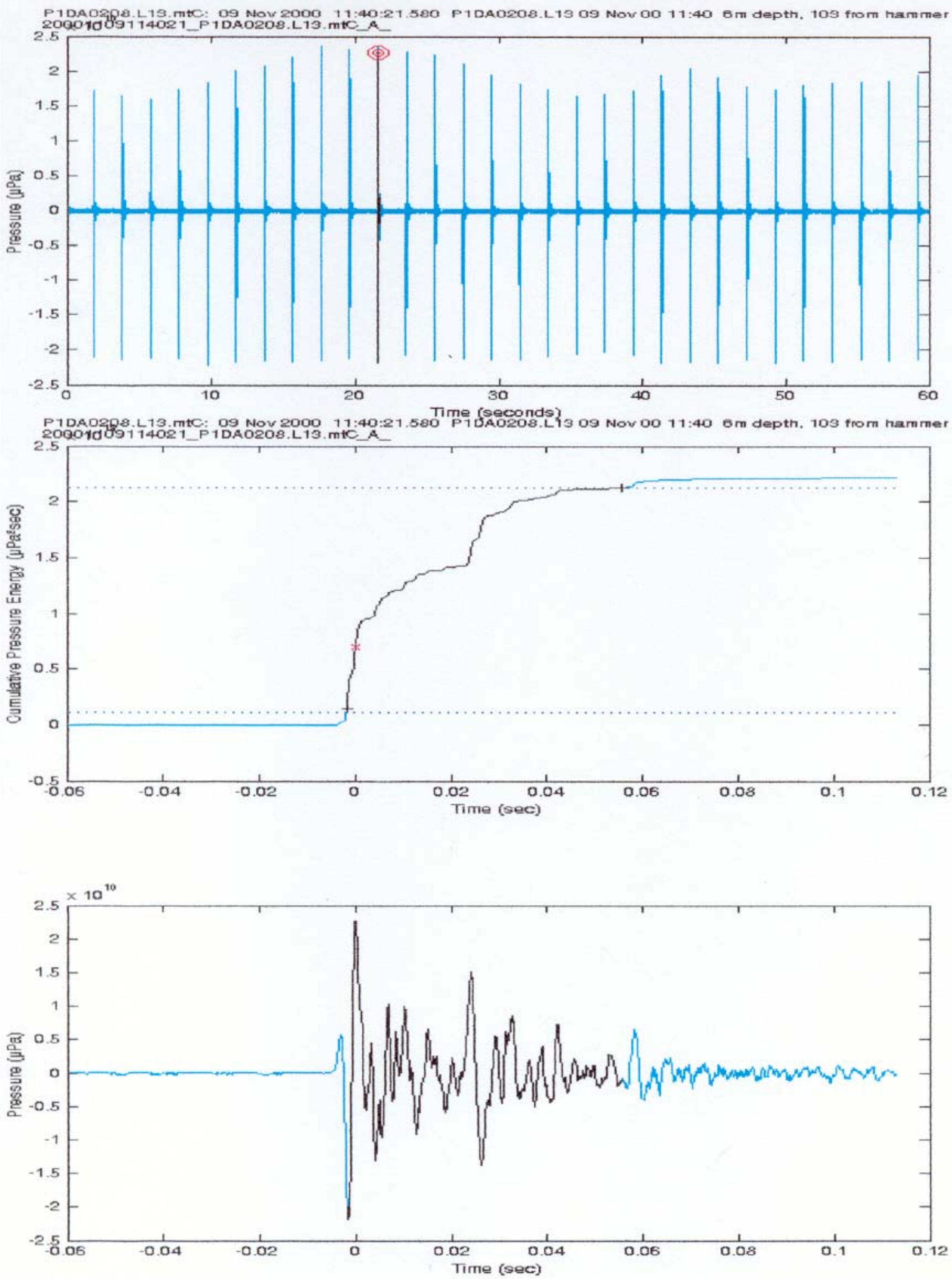
The limited data gathered with the bubble curtain in place indicated that there was no reduction in the overall linear sound level, the basis for the NMFS criterion level, as a result of the bubble curtain. It was effective in attenuating the higher frequency component of the noise (above about 800 Hz). It also changed the shape of the impulse (see Figures 9a-9b and D-2). It should be noted that water was relatively deep and currents were strong when data were gathered for the bubble curtain conditions. The bubble curtain may be more effective where water depth and current are less. Based on the limited data collected during the PIDP, the distance to the 190 dB Safety Zone should be considered to be the same with the bubble curtain as for no-mitigation.

The Gunderboom effectively reduced the RMS impulse sound pressure. A review of the data presented in Chapter 3 (in Illingworth & Rodkin, 2001) indicates that the distance to the 190 dB RMS (impulse) level was always less than 100 meters with the Gunderboom in place. It is not possible from the measured data to estimate the distance more accurately than to say that it is less than 100 meters with the Gunderboom in place. Table 2 summarizes the estimated distances to the 190 dB RMS (impulse) Level contour for, assuming no excess attenuation.

Table 2. Estimated Distance to 190 dB RMS (impulse) Level For Different Noise Attenuation Systems

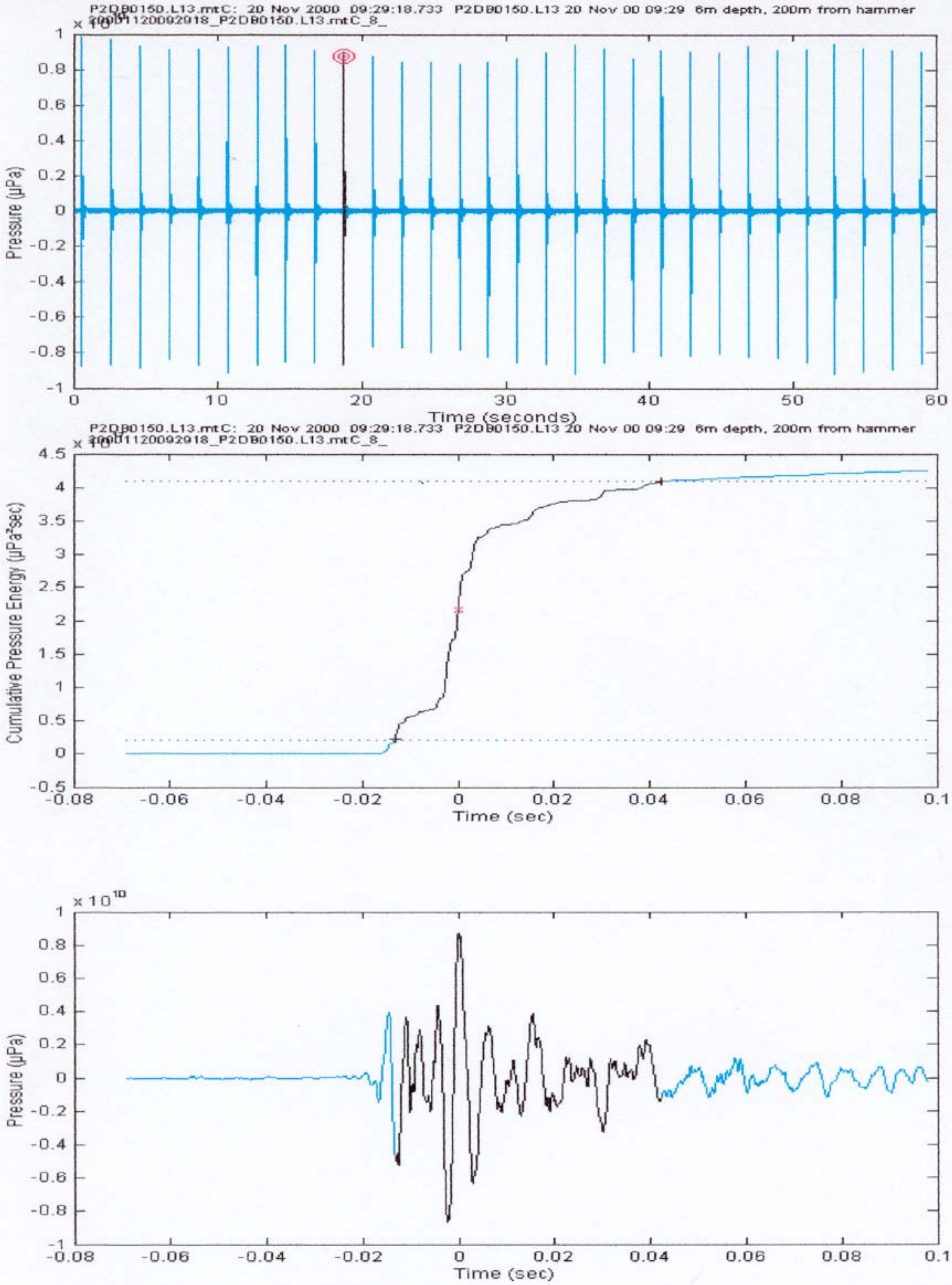
Hammer Energy k-Joules	Estimated Distance (Meters) to the 190 dB RMS (impulse) Levels Assuming No Excess Attenuation		
	No Sound Attenuation System	Bubble Curtain System	Gunderboom Operating
750	185	185	<100
1000	215	215	<100
1250	240	240	<100
1500	265	265	<100
1750	285	285	<100
Note: The bubble curtain changed the shape of the impulse and attenuated higher frequency noise, but did not change the overall sound pressure level. It is recommended that the distance to the 190 dB contour should not be assumed to be less than 185 meters regardless of hammer energy or hammer size.			

FIGURE 9a. ANALYSIS OF UNDERWATER NOISE - PILE 1D (UNMITIGATED), 100 METERS WEST 6-METER DEPTH



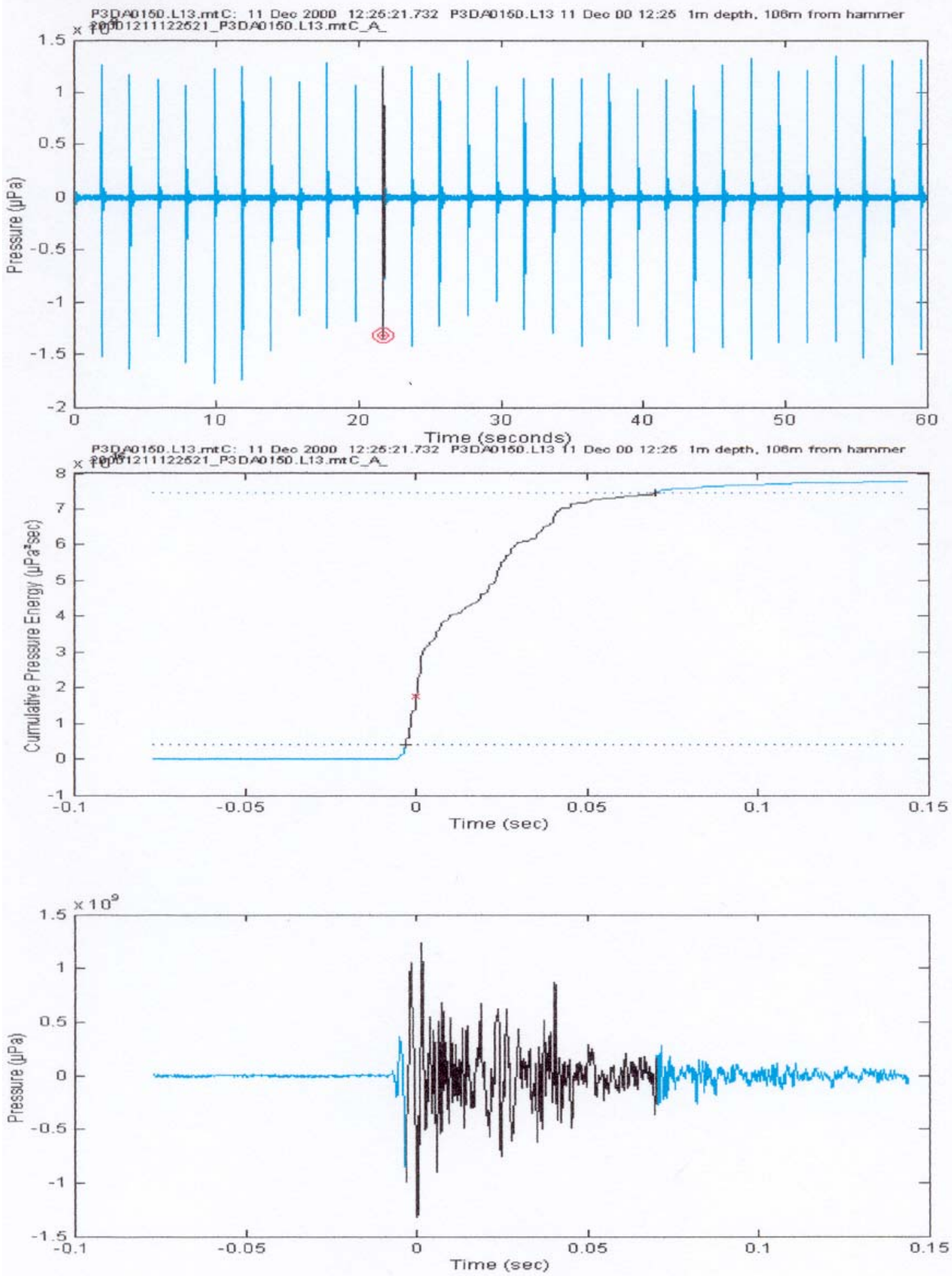
Analysis of Illingworth & Rodkin, Inc. tape recordings by Greenridge Sciences Inc.

FIGURE 9b. ANALYSIS OF UNDERWATER NOISE - PILE 2D (BUBBLE CURTAIN), 200 METERS WEST, 6-m DEPTH



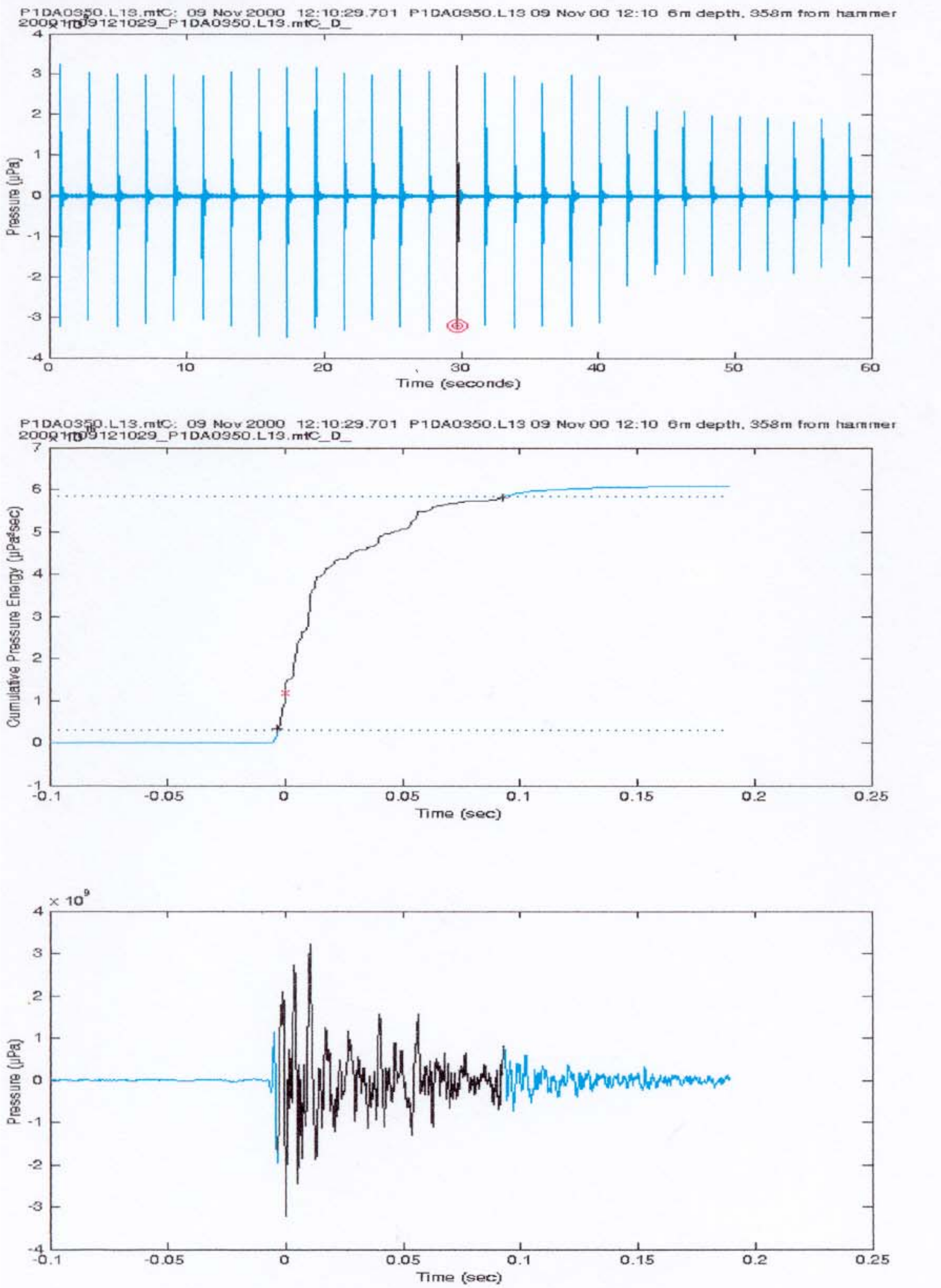
Analysis of Illingworth & Rodkin, Inc. tape recordings by Greenridge Sciences Inc.

FIGURE 9c. ANALYSIS OF UNDERWATER NOISE - PILE 3D (GUNDERBOOM™), 106 METERS EAST, 1-m DEPTH



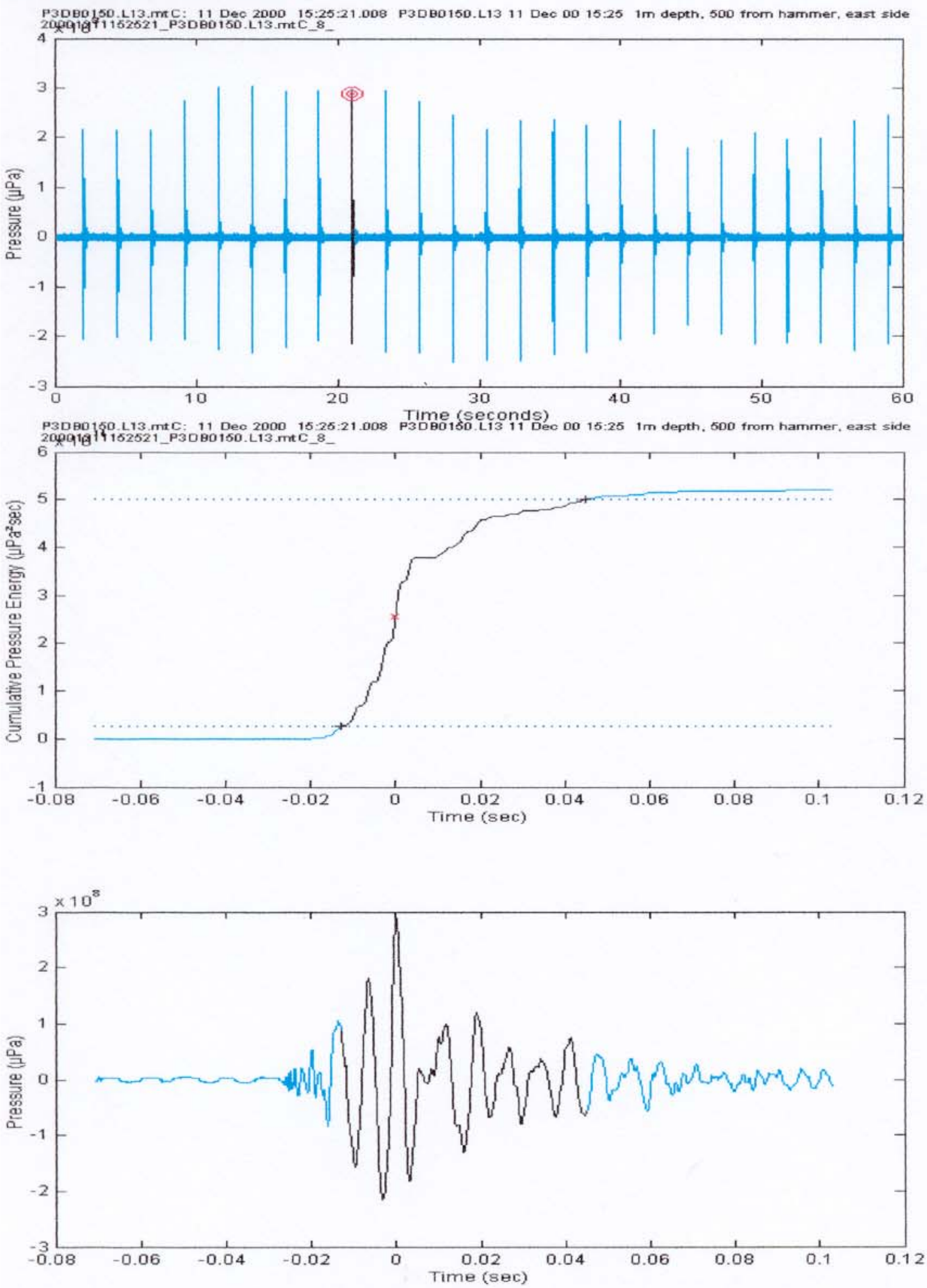
Analysis of Illingworth & Rodkin, Inc. tape recordings by Greenridge Sciences Inc.

FIGURE 9d. ANALYSIS OF UNDERWATER NOISE - PILE 1D (UNMITIGATED), 358 METERS NORTHWEST, 6-m DEPTH



Analysis of Illingworth & Rodkin, Inc. tape recordings by Greenridge Sciences Inc.

FIGURE 9e. ANALYSIS OF UNDERWATER NOISE - PILE 3D (GUNDERBOOM™), 500 METERS DISTANCE NORTH, 1-m DEPTH



Analysis of Illingworth & Rodkin, Inc. tape recordings by Greenridge Sciences Inc.

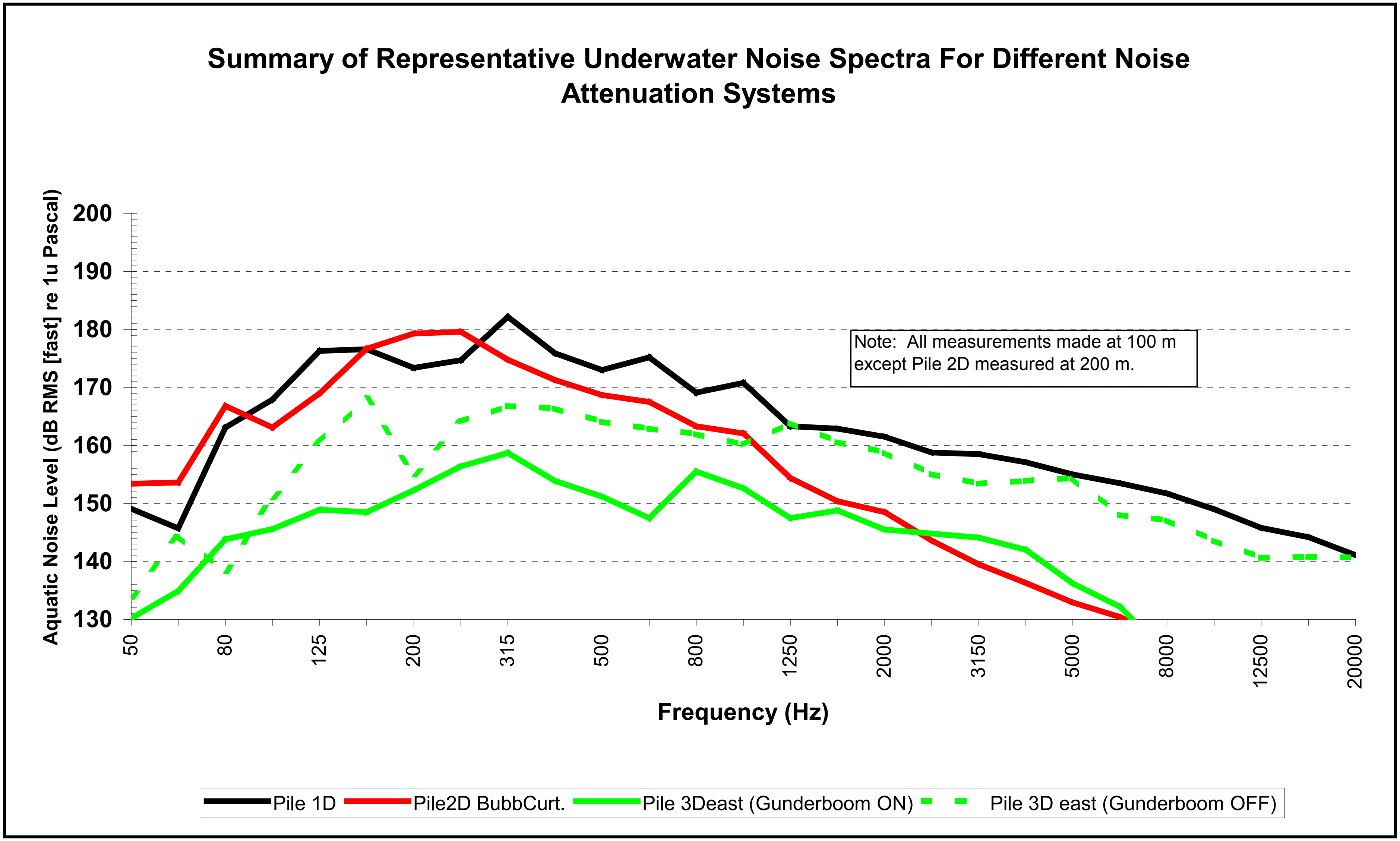

Summary of Representative Underwater Noise Spectra For Different Noise Attenuation Systems
Aquatic Noise Level (dB RMS [fast] re 1u Pascal)
200
190
180
170
160
150
140
130
50
80
125
200
315
500
800
1250
2000
3150
5000
8000
12500
20000
Frequency (Hz)
Note: All measurements made at 100 m except Pile 2D measured at 200 m.
Pile 1D
Pile2D BubbCurt.
Pile 3Deast (Gunderboom ON)
Pile 3D east (Gunderboom OFF)

Figure D-2